

Autonomous Oceanographic Sampling Network Development.

PI:

Samuel M. Smith.

Department of Ocean Engineering, Florida Atlantic University,
777 Glades Road, Boca Raton, Florida 33431.
561-367-3606 (tel) 561-367-3885 (fax)
smith@oe.fau.edu (email)

CO-PIs:

Stanley E. Dunn

Department of Ocean Engineering, Florida Atlantic University,
777 Glades Road, Boca Raton, Florida 33431.
561-367-3437(tel) 561-367-3885 (fax)
sdunn@oe.fau.edu (email)

K. Ganesan

Department of Computer Science and Engineering, Florida Atlantic University, 777
Glades Road, Boca Raton, Florida 33431.
561-367-3985 (tel) 561-367-2800 (fax)
ganesan@cse.fau.edu

ONR-3220M/AOSN

Award # N00014-96-1-5030

1 LONG-TERM GOALS

This proposal describes a program of work designed to contribute to the Navy's capabilities in mastering the mine warfare problem by developing and demonstrating fundamental capabilities needed for an Autonomous Oceanographic Sampling Network (AOSN). This includes the integration of AUV, ship, and moored sensors into a network test range. This range will support the development, testing, and demonstration of network components and communication capabilities. A link between the network and the Internet will enable remote monitoring and interaction. This test range will include acoustic and RF modem links. A set of network communication links will be implemented and demonstrated in turn culminating a multi-node network. This network will provide integrated information about the state of environmental variables pertinent to mine reconnaissance tasks and also facilitate adaptive search, survey, and sampling

2 OBJECTIVES

We wish to address the implications of networking elements such as AUVs, moorings, and support vessels and their component sub systems into a single network. As our capability matures we will focus on cooperation between network elements for more effective use of resources. A set of network communication links will be implemented and demonstrated in turn culminating in a multi-node network.

Show proof of concept as part of an ATD to demonstrate communication between an AUV and a

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 30 SEP 1997		2. REPORT TYPE		3. DATES COVERED 00-00-1997 to 00-00-1997	
4. TITLE AND SUBTITLE Autonomous Oceanographic Sampling Network Development				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Florida Atlantic University, Department of Ocean Engineering, 777 Glades Road, Boca Raton, FL, 33431				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 6	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Navy Submarine

3 APPROACH

This project focuses on the integration of sensors and systems into an AOSN type network based on a combination of wired, RF and acoustic modem links. This project implements the communications devices and provides appropriate interface software and hardware. The primary tasks are to implement the following communication links;

AUV to Ship via RF

Ship to Shore via RF

Shore to Internet Gateway

AUV to Ship via acoustic modem

AUV to Mooring via acoustic modem

AUV to AUV via acoustic modem

Routed Messaging via acoustic modem

FAU in collaboration with EdgeTech developed an acoustic modem designed for highly reliable communications. This modem is the basis of the acoustic links described above. The modems have a protocol that enables multiple access to the acoustic channel so that multiple AUVs and ships may communicate at the same time.

In addition, a modular payload section is used to house WHOI/NUWC's high speed acoustic modem to support acoustic communications experiments between an AUV and a support vessel. This experiment will lay the groundwork for eventual AUV to Submarine communications.

Moreover a next generation version of the EdgeTech modem will provide lower cost, smaller size, and higher bandwidth.

A gateway from the LONTalk network to the acoustic modem will provide virtually transparent access by any of the nodes on the LonTalk network to the acoustic channel. This consists of a SLTA and custom software that will translate the LONTalk protocol messages into the format required by the acoustic Modem.

Once the network is in operation, large amounts of geographically based data will be generated by the AUVs and moored sensors. FAU in a collaborative NSF funded research effort with CMU has developed an annotated map building system (AMBS). This is a set of software tools for geographic storage and retrieval of information. We will use these tools to support a tactical environmental database of the telemetry returned from the network. Eventually, a synthetic ocean environment simulation coupled with the database will facilitate the characterization of environmental structure and prototype adaptive sampling strategies. As these capabilities mature, adaptive and cooperative adaptive sampling strategies will be developed based on intelligent control techniques such as fuzzy case based reasoning. FAU has used this hybrid approach successfully to develop a robust reactive navigation system for an UUV.

4 WORK COMPLETED

Acquired, integrated and tested RF Ethernet modem link between AUV and ship. This used an Arlan 800kbps modem that supports tcp/ip. Antennae was modified to support in water use. Software was developed to support remote monitoring and modification of any variable in the AUV shared memory database. An RF Antennae has been incorporated into the mast of the pop up

DGPS antennae. This new RF antennae was used extensively for vehicle communications during the AUV Fest (NAVO hydrographic survey experiment).

A carrier sense multi-access protocol with priority based arbitration was specified by FAU and developed in collaboration with EdgeTech. This protocol allows a configurable number of modems to reliably share the same acoustic channel.

Side by side tests of the Data Sonics and EdgeTech Acoustic modems were conducted off the coast of Boca Raton in shallow water under a variety of conditions. Reliable communications were obtained for both modems over ranges of up to 1.8 km based on the conditions. The EdgeTech modem was selected for further development because they were already in house and supported multiple channel access.

The EdgeTech acoustic modem was integrated into the AUV in February. Communications were obtained out to 1 km ranges. Over the next two months repeated as sea trials revealed several electromechanical assembly and manufacturing defects and software bugs in the modem. These problems were eventually fixed. In April we performed reliable repeated two way communications between the AUV and a surface ship. The AUV mission was shut down remotely using a command sent with the acoustic modem. A second modem was integrated into another AUV. Repeated tests refined the transmission delays used in the protocol to increase the number of successful packets and throughput.

A COTS LonTalk powerline transceiver was used in a test project to see if it would work as a very low cost acoustic modem transceiver. The powerline transceiver uses a direct sequence spread spectrum protocol with a bandwidth of between 10 kHz to 90 kHz. A coupling circuit and off the self acoustic transducers were used in the test.

The NUWC ACOMS project required that the AUV go above 4 knots to accommodate the minimum speeds of Navy submarines. In response a set of speed tests were conducted in concert several modifications to the motor controller and propeller on the Ocean Explorer to increase its top speed.

One of the Ocean Explorer tail sections was sent to NUWC in July for self noise measurements to determine the potential interference with WHOI/NUWCs high speed acoustic modem.

In July the first demonstration off simultaneous multiple AUV to ship, and Ship to AUV acoustic communications were performed (two AUVs one ship). Later in July the first multiple AUV to AUV, AUV to ship, and ship to AUV communications were performed.

The AUV control software was modified to allow remote command of the AUV over the acoustic modem link. An efficient scalable binary command format was developed that allows a large number of commands and or data formats to be transmitted.

In August the WHOI/NUWC acoustic modem payload was integrated into the OEX and at sea operations were conducted off Fort Lauderdale. A towed array was used as a receive array on the AUV for high speed communications. Both high and low bandwidth communications were tested.

In September as part of the NAVO AUV Fest. The new acoustic modem command software was tested.

In October more advanced tests of the WHOI/NUWC acoustic modem payload were conducted at sea in Rhode Island. The AUV commands were ported to the WHOI/NUWC modem. Due to its increased bandwidth and packet size of the WHOI modem the compact binary form of the commands was not required.

5 RESULTS

The multiple vehicle acoustic modem tests off Boca Raton gave reliable performance (over 85% of packets successfully transmitted) at ranges up to 2 km in shallow water.

The multiple access protocol successfully allowed transparent use of the same acoustic bandwidth by multiple modems.

The EdgeTech modem protocol emphasizes reliability over bandwidth. Each packet has 5 bytes of usable data. The rest of the packet contains addressing and error correction information. The effective throughput is 1 packet every second or less depending on the range. However because of the high reliability regular use of the acoustic modem in AUV operations is enabled.

The AUV modem command software was used to remotely control the AUV throughout an entire mission. In addition position updates sent by the AUVs in the Hydrographic survey proved more reliable than the Acoustic tracking system and provided the needed confidence to continue the mission even when acoustic tracking was lost.

The AUV modem commands provided regular updates of vehicle status, position, and depth telemetry. In the October tests with the WHOI/NUWC modem real time CTD data was transmitted along with more vehicle status information. The WHOI modem regularly sustained data rates as high as 10 kbps.

The major differences between the two modems besides data rate are larger size, cost, & power requirements for the WHOI modem. Certainly in any AOSN scenario both types of modems have cost effective applications.

The very low cost powerline transceiver modem repeatedly provided communications at over 2 kbps up to 150 m. Given that the powerline transceiver itself is under \$100 the potential exists for expendable short range acoustic modems with the major cost being the acoustic transducer.

The new small size low cost spread spectrum FAU/EdgeTech acoustic modem has completed prototype testing. The final versions should be available for at sea testing before the end of the year.

6 IMPACT/APPLICATIONS

Low cost networking of AUVs has the potential to revolutionize the way data is collected in shallow water both for oceanographic and military missions.

The acoustic and RF modem communications capabilities we have demonstrated satisfies the related NAVO requirements for AUV hydrographic survey.

The basic acoustic communications technology infrastructure needed for AOSN is now developed. What remains is the development of control strategies and software to make Multi-AUV Cooperative adaptive sampling missions possible

7 TRANSITIONS

The ONR ACOMS ATD is well on its way to demonstrating AUV to Submarine acoustic communications. The follow on to the ATD completion would be integration into the fleet.

8 RELATED PROJECTS

AUV Navigation and Self-Motion in Shallow Water, ONR.

Autonomous Oceanographic Sampling Network Development, ONR.

Enhancing AUV Operational Capabilities, ONR.

Synoptic Data Collection With Multiple AUVs, ONR.

ACOMS Acoustic Communication between UUV and Submarine, ONR ATD.

ONR MURI on Nonlinear Control

USF Projects, CoBop, UK Autosub, WHOI Remus, MIT Odyssey

Advanced Machinery Control Architecture (ACMA) Laboratory Development for Automated Navy Ship Auxiliary System Control, Reconfiguration and Failure Recovery, ONR.

Dependable Network Topologies with Network Fragment Healing for Component Level Intelligent Distributed Control Systems for Naval Shipboard Automation, ONR.

9 REFERENCES

- [1] Charbel G. Rizk and Samuel M. Smith, "Automatic Design of Nonlinear Controllers with Optimal Global Performance Using Best Estimate Directed Search and Continued Propagation Cell Mapping", submitted to IEEE Transactions on Systems Man and Cybernetics 1997.
- [2] P.E. An, S.M. Smith, An Experimental Database of the Ocean Explorer AUV for Self-Motion Controlled Study, submitted to the IEEE Transactions on Oceanic Engineering, 1997.
- [3] S.M. Smith, K. Ganesan, P.E. An, & S.E. Dunn, "Strategies for Simultaneous Multiple AUV Operation and Control", *International Journal of Systems Science*, in Press.
- [4] P.E. An, S.M. Smith, S.E. dunn, X. Chen, & L. Mu, "New Experimental Results on Shallow-Water Autonomous Underwater Vehicle Motion in Controlled Environments," 7th International Offshore and Polar Engineering Conference, ISOPE-97, May 25-30, 1997, Honolulu Hawaii.
- [5] Submesoscale Coastal Ocean Dynamics Using Autonomous Underwater Vehicles and HF Radar, submitted to American Meteorological Society Conference, 1998
- [6] Hafen, M., Hine, A., Naar, D., 1997, Correlating geophysical, sedimentary and hydrologic characteristics of two areas of carbonate-siliciclastic sand-ridges on Florida's Gulf Coast: Abstracts of the American Geophysical Union National Meeting, San Francisco, December, 1997.
- [7] Mallinson, D., Naar, D., Hine, A., Hafen, M., Schock, S., Smith, S., Kloske, J., Gelfenbaum, G., Wilson, D., Lavoie, D., Richardson, M., 1997, Acoustic seafloor mapping using the AUV Ocean Explorer: Proceedings of the 10th International Symposium on Unmanned Untethered Submersible Technology.
- [8] Mallinson, D., Locker, S., Hafen, M., Naar, D., Hine, A., Lavoie, D., Schock, S., 1997 (in press), A high resolution geological and geophysical investigation of the Dry Tortugas carbonate depositional environment: *Geo-Marine Letters*, v. 17.
- [9] Mallinson, D., et al., 1997, Evaluating the acoustic remote sensing capabilities of the autonomous underwater vehicle Ocean Explorer: Abstracts of the American Geophysical Union National Meeting, San Francisco, December, 1997.
- [10] Mallinson, D., Hafen, M., Hine, A., Locker, S., 1997, The shallow subsurface geology of the Greater Tortugas area: Key West Campaign Workshop, Naval Research Laboratory, Stennis Space Center, MS.
- [11] P.E. An, S.M. Smith, J. Park, A. J. Healey, Asynchronous Data Fusion for AUV Navigation Via Heuristic Fuzzy Filtering Techniques, Oceans 97 Conference, Vol.1, pp.397-402, Nova Scotia, Canada, October, 1997
- [12] X. Chen, D. Marco, S. Smith, P.E. An, K. Ganesan, T. Healey, Six DOF Nonlinear AUV Simulation Toolbox, Oceans 97, Vol.2, pp.1070-1074, Conference, Nova Scotia, Canada, October, 1997.
- [13] S.M. Smith*, S. McPhail**, A. Healey***, R. Russell, LONTalk as a Standard Protocol for Underwater Sensor Platforms, Oceans 97, Conference, Nova Scotia, Canada, October, 1997.
- [14] J. Park, S. Smith, A. Neel, A Peer-to-Peer Communication Protocol for Underwater Acoustic Communication, Oceans 97, Conference, Nova Scotia, Canada, October, 1997.
- [15] S.M. Smith*, A. Healey, and D. Kronen, Experimental Results of an Inexpensive Short Baseline Acoustic Positioning System for AUV Navigation, Oceans 97, Conference, Nova Scotia, Canada, October, 1997
- [16] S.M. Smith, P.E. An, K. Ganesan, J. Park, & S.E. Dunn, "Design and Applications of Field Reconfigurable Autonomous Underwater Vehicles", Underwater Intervention Conference, February 17-19, 1997, Houston Texas.

- [17] C. Vasudevan, K. Ganesan, S.M. Smith, "Collision Avoidance by Dynamic Path Selection and Fuzzy Behavior Control", IEEE Transactions on Robotics and Automation, (submitted)
- [18] Samuel M. Smith, Modular UUV Architectures: Structure, Control, and Power; Issues and Experiences. SOC UUV Showcase and Exhibition, Southampton UK, Sept 24-25, 1997
- [19] D. M. Kronen, S. M. Smith*, J. C. Frankenfield, K. Bryan, R. T. Dunn, Introduction to the Docking Facility of the Ocean Explorer Series Autonomous Underwater Vehicles, UUST 97, Durham New Hampshire, Sept 1997.
- [20] Betzer, P.R., S.E. Dunn, S.M. Smith, R.H. Byrne, K.L. Carder, P.G. Coble, D.K. Costello, K.A. Fanning, and T.L. Hopkins. 1996. Sediment-Water Interactions on Continental Shelves. Presented at AGU Ocean Sciences Meeting, San Diego, California, 12-16 February 1996.
- [21] Peacock T.G., D.K. Costello, K.L. Carder, T. Carney, and J. Kloske.
- [22] A new Vessel for Support of Unmanned Underwater Vehicle Operations.
- [23] Abstract Submitted to 1998 AGU Ocean Sciences Meeting.
- [24] Charbel Rizk, Best Estimate Directed Search and Continued Propagation Cell Mapping for Optimal Control, FAU PHD Dissertation August 1997.
- [25] Kevin White, "Design and Implementation of an Altitude Flight Controller for the FAU Ocean Voyager II", FAU Masters Thesis(April 96).
- [26] Thomas C. Flanigan, Development and Analysis of Real Time Software for Autonomous Underwater Vehicles, FAU Masters Thesis.
- [27] S. M. Smith, P. E. An, D. Kronen, K. Ganesan, J. Park, S. E. Dunn, "The Development of Autonomous Underwater Vehicle Based Survey and Sampling Capabilities for Coastal Exploration", Oceans 96, Ft. Lauderdale, FL, September, 1996.
- [28] P. E. An, A. J. Healey, S. M. Smith, S. E. Dunn, "New Experimental Results on GPS/INS Integration Using Ocean Voyager II AUV", IEEE AUV 96, pp.249-255, Monterey, CA, June, 1996.
- [29] K. Ganesan, S.M. Smith, K. White, & T. Flanigan, "A Pragmatic Software Architecture for UUVs", IEEE AUV 96, pp., Monterey, CA, June, 1996.
- [30] Ken Holappa, Manhar Dhanak, Samuel Smith and Edgar An, "Ocean Flow Measurement Using and Autonomous Underwater Vehicle" IEEE AUV 96, pp. 424-428, Monterey, CA, June, 1996.
- [31] K.A. White, S.M. Smith, K. Ganesan, D. Dronen, G.J.S. Rae & R.M. Langenbach, "Performance Results of a Fuzzy Behavioral altitude Flight Controller and Rendezvous & Docking of an Autonomous Underwater Vehicle with Fuzzy Control", IEEE AUV 96, pp., Monterey, CA, June, 1996.
- [32] S. M. Smith, K. Ganesan, S. E. Dunn, P. E. An, "Strategies for Simultaneous Multiple AUV Operation and Control", IARP96, France, April, 1996.
- [33] Min Xu, "High Performance and Robust Control" Ph.D. Dissertation Florida Atlantic University College of Engineering, April 1996.
- [34] P. E. An, S. M. Smith, S. E. Dunn, "A Quantitative Measure of Sea-State Effect on Small Autonomous Underwater Vehicle Motion in Shallow Water", Oceanlog International 96, pp.211-233, Brighton, U.K., March, 1996.
- [35] S. M. Smith, S. E. Dunn, P. E. An, "Data Collection with Multiple AUVs for Coastal Oceanography", Oceanology International 96, pp.263-279, Brighton, U.K., March, 1996.
- [36] C. Vasudevan and K. Ganesan, "Case-Based Path Planning for Autonomous Underwater Vehicles", Autonomous Robots Journal Vol 3, pp. 79-89, 1996.
- [37] P.R. Betzer, S.E. Dunn, S.M. Smith, R.H. Byrne, K.L. Carder, P.G. Coble, D.K. Costello, K.A. Fanning, T.L. Hopkins, "Sediment - Water Interaction on Continental Shelves." American Geophysical Union 1996 Ocean Sciences Meeting.